J Raptor Res. 38(1):62–68
© 2004 The Raptor Research Foundation, Inc.

ELEVATED LEAD LEVELS IN URBAN HOUSE SPARROWS: A THREAT TO SHARP-SHINNED HAWKS AND MERLINS?

RICHARD B. CHANDLER, ALLAN M. STRONG,[1] AND CARLIN C. KAUFMAN
University of Vermont, School of Natural Resources, Wildlife and Fisheries Biology Program, Burlington, Vermont 05405 U.S.A.

ABSTRACT.—In urban environments, lead (Pb) has been recognized as a health threat to humans as well as wildlife. Although this hazard has waned since the banning of leaded gasoline and paint in the 1970s, soil and atmospheric Pb concentrations have remained higher in disturbed habitats than in exurban habitats. Our study evaluated the threat of Pb exposure to Sharp-shinned Hawks (*Accipiter striatus*) and Merlins (*Falco columbarius*) by measuring blood Pb concentrations of the House Sparrow (*Passer domesticus*), a favored prey species and a Eurasian exotic with a history of elevated Pb levels. In 2002, we found blood Pb concentrations of urban House Sparrows in Vermont, U.S.A., were significantly (4.5-fold) greater than in an agricultural control group. Because urban-dwelling Sharp-shinned Hawks and Merlins both selectively prey upon House Sparrows, they may be accumulating Pb. Analysis of 1970–2002 Christmas Bird Count data confirmed an increase in wintering Sharp-shinned Hawks in Vermont and found a significant correlation (r^2 = 0.456, P < 0.05) between the rate of Sharp-shinned Hawk population increase and the mean abundance of House Sparrows. However, House Finch (*Carpodacus mexicanus)* abundance and rate of increase were more strongly related to the Sharp-shinned Hawk increase (r^2 = 0.732, P < 0.001 and r^2 = 0.731, P < 0.001; respectively). We found no positive correlation between Sharp-shinned Hawks and two common native New England residents, Black-capped Chickadee (*Poecile atricapilla*) and Purple Finch (*Carpodacus purpureus*), suggesting introduced prey species may partially explain the mechanism behind the "short-stopping" phenomenon occurring in a portion of the Sharp-shinned Hawk's range. The degree to which the exposure to lead-laden House Sparrows threatens urban raptor populations is unclear, and we recommend a more detailed examination of the contaminant levels in urban-dwelling raptors.

KEY WORDS: *Sharp-shinned Hawk;* Accipiter striatus; *House Sparrow;* Passer domesticus; *Merlin;* Falco columbarius; *lead; migration; Pb; urban ecosystem.*

NIVELES ELEVADOS DE PLOMO EN GORRIONES CASEROS URBANOS: ¿UNA AMENAZA PARA LOS GAVILANES Y LOS HALCONES PALOMEROS?

RESUMEN.—En los ambientes urbanos, el Plomo (Pb) ha sido reconocido como una amenaza para la salud humana y de la vida silvestre. Aunque este peligro ha disminuido desde la prohibición de la gasolina y pinturas con plomo en los 70's, las concentraciones de plomo en el suelo y la atmósfera han permanecido más altos en hábitats alterados que en hábitats al exterior de las urbes. Nuestro estudio evaluó la amenaza por exposición a plomo de los gavilanes (*Accipiter striatus*) y los halcones palomeros (*Falco columbarius*)a través de la medición de las concentraciones de plomo en la sangre de gorriones caseros (*Passer domesticus*), una presa predilecta, además de ser una especie exótica Euroasiática con una historia de elevados niveles de plomo. En el 2002, encontramos que las concentraciones de plomo en la sangre de gorriones urbanos en Vermont, U.S.A., fueron significativamente (4–5 veces) más grandes que en un grupo control ubicado en una zona agrícola. Debido a que los gavilanes y halcones palomeros que habitan zonas urbanas depredan selectivamente sobre los gorriones caseros, pueden ellos estar acumulando plomo. El análisis de los datos de los conteos navideños de aves de 1970–2002 confirman un incremento de los gavilanes invernantes en Vermont y encontramos una correlación significativa (r^2 = 0.456, P < 0.05) entre la tasa de incremento de la población de gavilanes y la abundancia media de gorriones caseros. Sin embargo, la abundancia y la tasa de incremento de los pinzones caseros (*Carpodacus mexicanus*) estuvo mas fuertemente relacionada al incremento de los gavilanes (r^2 = 0.732, P < 0.001 y r^2 = 0.731, P < 0.001; respectivamente). No encontramos correlaciones positivas entre los azores

[1] E-mail address: allan.strong@uvm.edu

y dos aves nativas, residentes comunes de New England, los paros de gorra negra (*Poecile atricapilla*) y los pinzones purpúreos (*Carpodacus purpureus*), sugiriendo que las especies presa introducidas pueden explicar parcialmente el mecanismo que se encuentra detrás del fenómeno de "parada corta" que ocurre en una porción del rango del gavilan. El grado en el cual la exposición a gorriones caseros cargados con plomo amenaza a las poblaciones de rapaces urbanas, no es claro y recomendamos un examen más detallado de los niveles de contaminantes en las rapaces que habitan en las urbes.

[Traducción de César Márquez]

Urban ecosystems are highly-modified landscapes characterized by severe disturbances and high proportions of introduced species (Beisinger and Osborne 1982, Gilbert 1989, Blair 1996). These ecosystems are circulation and accumulation sites for a suite of environmental contaminants including lead (Pb), a toxic trace metal remaining in street dust and soils from the leaded gas era and from the use of leaded paints (de Eduardo et al. 1997). Typically, urban ecosystems do not provide high-quality habitat for most wildlife species as evidenced by low species richness (Beisinger and Osborne 1982, Blair 1996); however, as cities, towns, and agricultural expansion have impacted the natural landscape, new or modified niches have arisen. Within the United States, many native wildlife species from a variety of taxa are adapting to human-modified ecosystems and, in certain cases, have become successful at exploiting these new niches. Raptors such as Merlins (*Falco columbarius*), Peregrine Falcons (*Falco peregrinus*), Red-tailed Hawks (*Buteo jamaicensis*), Cooper's Hawks (*Accipiter cooperii*), Mississippi Kites (*Ictinia mississippiensis*), and Eastern Screech-Owls (*Otus asio*) have altered their habitat use patterns to take advantage of urban resources (DeMent et al. 1986, Sodhi and Oliphant 1993, Viverette et al. 1996, Boal and Mannan 1999, Kaplan 2000, Berger 2001).

Although these cases suggest successful adaptation to urban environments, the costs to raptors in urban ecosystems have not been fully evaluated. Boal and Mannan (1999) illuminated a few of the environmental threats facing urban Cooper's Hawks, but they focused primarily on human activity around nests, automobile collisions, and diseases. Other sublethal effects may also counteract short-term population increases. In this study, we examined the potential toxicological threat posed by elevated Pb levels in a common, synanthropic prey species, the House Sparrow (*Passer domesticus*). House Sparrows were chosen as a focal species because they are a preferred prey item for Merlins and Sharp-shinned Hawks (*Accipiter striatus*) in developed landscapes (Sodhi and Oliphant 1993, Dunn and Tessaglia 1994) and we have witnessed several Merlin and Sharp-shinned Hawk attacks on House Sparrows within our study area. Additionally, documentation of elevated Pb levels among urban songbirds (Getz et al. 1977), a Peregrine Falcon that contracted a *Pseudomonas* infection as a result of preying on Rock Doves (*Columba livia*) with elevated Pb levels (DeMent et al. 1986), and the documentation of at least seven species of North American raptors that have died from Pb poisoning (Locke and Friend 1992) warrant further investigation of the role of House Sparrows in Pb accumulation in raptors.

We paid special attention to Sharp-shinned Hawks because of the recently documented "short-stopping" phenomenon, in which a portion of their eastern population has reduced its migration distance and remained in New England throughout the winter (Duncan 1996). This short-stopping appears to explain partially the substantial decreases in numbers of Sharp-shinned Hawks at fall hawk watch sites along the East Coast during the past two decades (Duncan 1996, Viverette et al. 1996) and may be tied to increased prey availability in urban ecosystems. Although the ecological mechanism behind the short-stopping phenomenon has yet to be investigated, if selected urban prey species exhibit higher Pb loads than do exurban prey, Sharp-shinned Hawk populations could face a toxicological risk.

Previous ornithological studies (e.g., DeMent et al. 1986, Sodhi and Oliphant 1993) in urban environments and our observations of raptors in urban regions of Vermont led us to the prediction that House Sparrows may pose a toxicological threat to urban Sharp-shinned Hawks and Merlins. Consequently, we examined the following hypotheses: (1) a portion of the Sharp-shinned Hawk population has shifted its migratory behavior in response to the increased food availability associated with human-modified environments, and (2) in urban areas, Pb continues to be a threatening trace element to wildlife, persisting in some avian food chains. Our goal was to determine whether Pb is persistent in the prey base of these two raptors, and if so, are wintering populations consuming House Sparrows affected by potential toxicological threats?

METHODS

We analyzed Christmas Bird Count (CBC) data from 1970–2002 in 11 of 18 Vermont count circles (National Audubon Society 2002). These 11 circles represent all those with data from at least 1975, the first year of Duncan's (1996) analysis of the Sharp-shinned Hawk short-stopping phenomenon. Vermont was selected as a representative study region in New England because its wintering Sharp-shinned Hawk population has increased significantly (Duncan 1996). In Vermont, Merlin populations are not large enough in winter to analyze using CBC data. The mean annual rate of Sharp-shinned Hawk population increase was determined for each CBC circle by regressing the number of birds/party hr on count year. Rates of Sharp-shinned Hawk increase were regressed on mean abundances and mean annual rates of change of House Sparrows and three reference species: House Finches (*Carpodacus mexicanus*), Purple Finches (*Carpodacus purpureus*) and Black-capped Chickadees (*Poecile atricapilla*), with each CBC circle assumed to be an independent data point. Mean abundance for each CBC circle was calculated as the mean number of individuals encountered (1970–2002)/party hr. This measure allows for relative rather than absolute comparisons of species abundances among CBC circles. Mean annual rates of change were calculated following the same methodology as defined above for Sharp-shinned Hawks.

We selected House Sparrows as a focal species based upon our observations of urban predator-prey interactions, their high abundance in urban areas of New England, and their history of Pb accumulation (Getz et al. 1977). House Sparrows likely accumulate Pb when ingesting grit for digestive purposes (Gionfriddo and Best 1995). This species is also regularly taken by both Merlins and Sharp-shinned Hawks in human modified habitats and falls within the preferred size class of prey taken by both raptors (Lowther and Cink 1992, Sodhi and Oliphant 1993, Dunn and Tessaglia 1994).

Our reference species were all winter residents and recognized prey species of Sharp-shinned Hawks (Bildstein and Meyer 2000). We chose these species because their habitat associations differ from those of House Sparrows, making them appropriate species for evaluating the hypothesis that Sharp-shinned Hawks are short-stopping in response to the abundance of urban exotics. Black-capped Chickadees are a common winter resident in New England associated with natural and human-modified habitats. Purple Finches are generally considered forest dwelling species, although they are also a common visitor to birdfeeders. House Finches are the most synanthropic of the references species, found in urban and residential areas but are more readily found in suburban areas than House Sparrows (Blair 1996).

Pb concentrations in venous blood are good indicators of acute or chronic environmental exposure as well as of body Pb burden (Reiser and Temple 1981, Hunter 1986). To examine Pb levels in House Sparrows, we collected blood samples from birds in three locations. Our experimental sites were located in two urban areas in Burlington, Vermont; one in a high-density residential district and the other in the business district. Busy roads and sidewalks were features common to both locations, and within these areas House Sparrows seemed to aggregate around low, dense vegetation. The residential district was a primarily residential neighborhood interspersed with some small businesses. The netting site within the business district was close to a central park, large parking lots, and buildings taller than 10 m. Small convenience stores, banks, and restaurants were more common here than within the residential district. Our reference site was a conventional dairy farm in a rural region of Vermont, approximately 55 km southeast of Burlington. We used mist nets to capture House Sparrows prior to collecting <1 dl of blood from the alar vein of each bird in heparanized capillary tubes from a small puncture made using a 22-gauge needle. The samples were frozen (below −20°C) until analyzed.

All samples were diluted five-fold and analyzed for Pb on a Perkin-Elmer SIMAA 6000 graphite furnace atomic absorption instrument equipped with a transversely-heated furnace, Zeeman background correction, autosampler, and electrodeless discharge lamp. A matrix modifier consisting of ammonium phosphate, Triton X-100, and nitric acid was mixed with all samples. Quality-control samples included a method blank, laboratory control samples, and a standard reference (NIST 955b1, Lead in Bovine Blood). Blood mass was low, preventing analysis of matrix spike or duplicate samples. However, two capillary tubes from the same individual were used as field duplicates, which showed identical blood Pb concentrations. Laboratory Quality Assurance data were acceptable and showed low blank levels and good accuracy. Concentration units are reported in parts per million (mg/l) with a detection limit of 0.005 ppm.

Because of the paucity of information available concerning raptors in urban environments, we have included observations from the field that indicated either modified foraging behaviors or potential threats to these species. All observations were collected opportunistically by the authors on raptors inside Burlington's city limits.

RESULTS

Sharp-shinned Hawks showed significant increases in 9 of 11 Vermont count circles between 1970 and 2002. These rates of change were positively correlated with mean winter House Sparrow abundances ($F = 8.2$, df = 1, 9, $P < 0.05$, $r^2 = 0.476$; Fig. 1), though not with House Sparrow mean annual rate of change ($F = 0.171$, df = 1, 9, $P > 0.6$, $r^2 = 0.019$). They were inversely correlated with mean abundance of Purple Finches ($F = 6.7$, df = 1, 9, $P < 0.05$, $r^2 = 0.4255$); and highly positively related with both mean abundance ($F = 24.5$, df = 1, 9, $P < 0.001$, $r^2 = 0.732$; Fig. 2) and mean annual rate of change ($F = 24.4$, df = 1, 9, $P < 0.001$, $r^2 = 0.731$; Fig. 2) of House Finches. The Sharp-shinned Hawk population increase was not

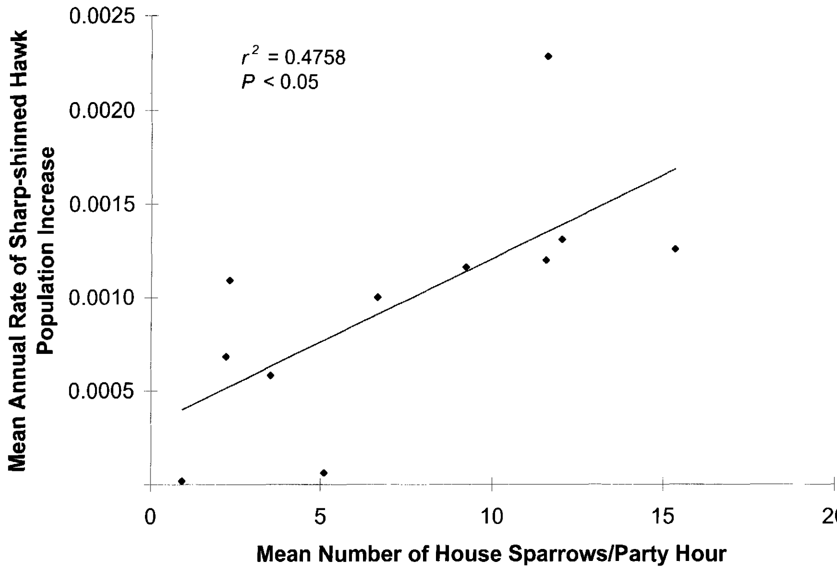

Figure 1. Rate of Sharp-shinned Hawk population change was significantly correlated with abundance of House Sparrows in Vermont Christmas Bird Counts, 1975–2002.

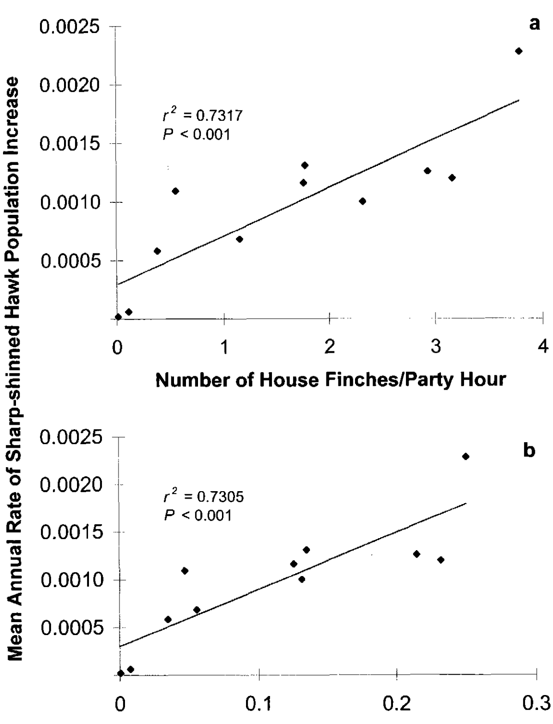

Figure 2. Rate of Sharp-shinned Hawk population change was significantly correlated with abundance (a) and rate of change (b) of House Finches in Vermont Christmas Bird Counts, 1975–2002.

correlated with either abundance or mean annual rate of change in Black-capped Chickadees (F = 0.1, df = 1, 9, $P > 0.7$, $r^2 = 0.012$; F = 0.5, df = 1, 9, $P > 0.45$, $r^2 = 0.052$; respectively) or with mean annual rate of change of Purple Finches (F = 4.9, df = 1, 9, $P > 0.05$, $r^2 = 0.354$).

Blood Pb concentration differed among House Sparrows in the three study groups (F = 10.16, df = 2, 24, $P < 0.001$; Table 1). We found no difference in Pb concentrations between the two urban groups (t = 0.873, df = 11.7, P = 0.40); therefore, we combined residential district (N = 8) and business district (N = 8) into a single urban category. Blood Pb concentrations were more than 450%

Table 1. Blood lead concentrations in House Sparrows in Vermont, 2002 varied significantly among three habitats.

LOCATION	N	MEAN BLOOD PB CONCENTRATION ± SD (ppm)[a]
Urban, business district	8	0.083 ± 0.068
Urban, high-density residential district	8	0.108 ± 0.042
Urban combined	16	0.095 ± 0.053
Reference	11	0.021 ± 0.012

[a] $F_{2,24}$ = 10.16, $P < 0.001$.

greater in urban ($N = 16$) than agricultural ($N = 11$) House Sparrows ($t = 5.183$, df = 16.9, $P < 0.001$). Despite significantly higher blood Pb concentrations, the combined urban mean of 0.0953 ppm is probably not high enough to affect survival or reproductive rates negatively (Getz et al. 1977, Redig 1984). However, we found substantial individual variation, with one individual exhibiting a blood Pb concentration of 0.209 ppm.

Sharp-shinned Hawks, Cooper's Hawks, Merlins, Peregrine Falcons, Red-tailed Hawks, and Bald Eagles (*Haliaeetus leucocephalus*) were all observed within Burlington's urban zone during the winter 2001–02. On five occasions, Sharp-shinned Hawks or Merlins were observed either hunting or feeding upon House Sparrows. We did not observe these two species pursuing prey species other than House Sparrows.

DISCUSSION

Our results provide support for the hypothesis that population increases in wintering Sharp-shinned Hawk populations in Vermont are strongly correlated with prey availability in human-modified environments. Our anecdotal observations of these raptors hunting in urban environments, combined with previous studies showing House Sparrows to be the codominant prey species taken by Sharp-shinned Hawks at birdfeeders (Dunn and Tessaglia 1994) suggest that large House Sparrow populations provide a plausible causal mechanism for the increase of winter raptor populations. Though we did demonstrate that Sharp-shinned Hawks increased proportionally with mean densities of House Sparrows, we found that House Finch abundances and rates of change were more strongly related to changes in raptor numbers. That we found no significant relationship with mean annual rate of House Sparrow increase supports the hypothesis that House Finches were primarily responsible for attracting these hawks into urban and suburban areas. However, we also suggest that House Sparrows are an important food source for raptors within these modified habitats. Merlins in particular are known to feed almost exclusively on House Sparrows, which can comprise more than 70% of prey items taken in urban environments (Sodhi and Oliphant 1993). In fact, in Vermont, there was a strong correlation between the rate of House Finch increase and mean abundance of House Sparrows ($F = 31.8$, df = 1, 9, $P < 0.01$, $r^2 = 0.76$). Consequently, raptors that have adapted to these modified environments may have responded to increasing House Finch populations, which also likely enabled them to exploit abundant, stable House Sparrow populations. Thus, it is plausible that both species of raptors are curtailing their southward migrations to take advantage of the increased introduced prey base.

Theoretical arguments regarding the costs and benefits of migration support our hypothesis. Raptors, like other migratory birds, are believed to depart their breeding grounds in response to the deteriorating conditions brought about by winter climates (Rappole 1995). Because Neotropical migratory songbirds typically comprise the vast majority of Sharp-shinned Hawk's diet (Bildstein and Meyer 2000), it is probable that fall migration of these prey species is the most important reason for this raptor's migration. Assuming migration is a trade-off between breeding season productivity and mortality during migration and the nonbreeding season, it is possible that increased food resources at higher latitudes (e.g., House Sparrows and House Finches) might alter the cost-benefit ratio of migration such that winter mortality at higher latitudes is less than or equal to migration mortality + winter mortality at lower latitudes. Thus, Sharp-shinned Hawks could be expected to increase in areas with high populations of resident prey species. The Black-capped Chickadee and the Purple Finch, two common winter residents in New England, do not appear to be associated with winter population increases of Sharp-shinned Hawks. Rather, our data suggested that House Sparrow and House Finch populations provided the prey base that has led to increased winter populations of Sharp-shinned Hawks in Vermont, as a result of short-stopping migratory patterns. Because of the differences between these prey species' habitat associations, we conclude that the increase in hawks appears to be most rapid in urban and residential areas. The inverse relationship between Purple Finches and Sharp-shinned Hawks may also indicate that the short-stop phenomenon is not occurring in natural habitats.

Our results also showed that blood Pb concentrations were measurable in House Sparrow populations, and compared to rural populations, were ca. 4.5× higher in urban areas (Table 1). Thus, despite the fact that Pb has been banned in gasoline and paint for over 20 yr, environmental sources are still sufficiently abundant to show movement into higher tropic levels. However, this elevated Pb level was not lethally threatening to House Sparrows, which have been shown to sustain higher concentrations (Getz et al. 1977). It is plausible that sublethal effects might make individuals with elevated blood Pb concentrations more susceptible to predation (Peterle 1991:108).

Although our results showed an increase in Sharp-shinned Hawk populations in areas with high House Sparrow populations and elevated blood Pb concentrations in this prey species, the threat to urban raptors was equivocal. Several toxicity studies of raptors have indicated that in controlled conditions, Pb can biomagnify to threatening or lethal levels when lead-laden prey species were consumed. The infection leading to the death of an urban Peregrine Falcon was contracted as a result of its susceptibility to infection from continual depredation of Rock Doves with blood Pb levels approximately nine times higher ($\bar{x}$ = 0.901 ppm) than those found in our study of House Sparrows (DeMent et al. 1986). A controlled toxicological experiment in which a Pb acetate trihydrate solution was administered to nine raptors of three species found that blood Pb levels between 5 and 8 ppm led to clinical signs in five individuals and death in four (Reiser and Temple 1981).

Conflicting information on accumulation rates and effects of lead are common. These discrepancies are typically explained by differences in study design and interspecific variation in susceptibility to Pb (Peterle 1991). Franson et al. (1983), for instance, reported no major physiological effects on American Kestrels (*Falco sparverius*) with blood Pb levels as high as 33 ppm. Wild predatory birds may be affected differently by contamination than captive birds because of differences in metabolic rates and behaviors. For example, predators may not be able to forage as effectively with high contaminant loads (Peterle 1991). The relatively short duration of laboratory experiments also may not reveal sublethal risks posed by long-term Pb exposure. The Peregrine Falcon death also suggested that risk of infectious disease may have increased with increased Pb load, a threat possibly exacerbated in the wild. These factors make it difficult to determine the threat to raptors feeding on House Sparrows with the blood Pb concentrations reported in this paper. Therefore, we suggest that the probability of biomagnification of lead is worthy of further investigation.

Urban raptors may face a significant toxicological threat if, as our data indicate, high levels of toxins are present in urban prey species and a significant proportion of a raptor population alters its migratory behavior to exploit these prey. The risks of such a scenario is impossible to assess without measuring the actual Pb levels in a population of urban raptors (Newton 1998), and unfortunately no such data have been collected. We also note that Pb levels have not been measured in House Finches. These uncertainties, as well as the lack of knowledge of biologically incorporated Pb intake rates in birds of prey indicate the need for stronger avian bioaccumulation models and more research into urban ecosystems. Data on sublethal physiological, behavioral, and reproductive effects (e.g., Burger 1995) are also needed. We suggest that a study be performed similar to that of Wood et al. (1996), in which thorough toxicological tests are conducted on New England's wintering urban avian communities, especially birds of prey. This would allow for a detailed comparison of contaminant levels in urban and exurban environments. Although Wood et al. (1996) concluded that decreased numbers of migratory Sharp-shinned Hawks could not be explained by toxicological factors, nonmigratory individuals were not sampled in that study; however, this may be the population segment most at risk to increased Pb levels.

ACKNOWLEDGMENTS

The University of Vermont's Honors College and Office of Sponsored Programs provided financial support for this project and deserves recognition for its efforts to provide support to undergraduates interested in scientific research. Thanks to the National Audubon Society and the Cornell Laboratory of Ornithology for use of CBC data and the many Christmas Bird Count volunteers for their continued effort. Robert Taylor at Texas A&M conducted the Pb analyses with patience and humor. We thank Monument Farms and the residents of Burlington, Vermont for their resources, suggestions, and enthusiasm. For technical assistance and comments we thank Terri Donovan and Peter Jones. The manuscript was greatly improved with the suggestions of our referees: M Martell, R.W. Mannan, and T.J. McBride. Finally, Mary Willson and the Project Chucao crew were instrumental in editing the manuscript. Mist netting and blood sampling was done in accordance with the guidelines of the University of Vermont's Institutional Animal Care and Use Committee (IACUC No. 02-092).

LITERATURE CITED

BEISINGER, S.R. AND D.R. OSBORNE. 1982. Effects of urbanization on avian community organization. *Condor* 84:75–83.

BERGER, C. 2001. Urban raptors. *Natl. Wildl.* 39:30–37.

BILDSTEIN, K.L. AND K. MEYER. 2000. Sharp-shinned Hawk

(*Accipiter striatus*). *In* A. Poole and F. Gill [EDS.], The birds of North America, No. 482. The birds of North America, Inc. Philadelphia, PA U.S.A.

BLAIR, R.B. 1996. Land use and avian species diversity along an urban gradient. *Ecol. Appl.* 6:506–519.

BOAL, C.W. AND R.W. MANNAN. 1999. Comparative breeding ecology of Cooper's Hawks in urban and exurban areas of southeastern Arizona. *J. Wildl. Manage.* 63:77–84.

BURGER, J. 1995. A risk assessment for lead in birds. *J. Toxicol. Environ. Health* 45:369–396.

DE EDUARDO, M., J.F. LLAMAS, E. CHACON, T. BERG, S. LARSSEN, O. ROYSET, AND M. VADSET. 1997. Origin and patterns of distribution of trace elements in street dust: unleaded petrol and urban lead. *Atmos. Environ.* 31:2733–2740.

DEMENT, S.H., J. CHISOLM, J. BARBER, AND J. STRANDBERG. 1986. Lead exposure in an "urban" Peregrine Falcon and its avian prey. *J. Wildl. Dis.* 22:238–244.

DUNCAN, C.D. 1996. Changes in winter abundance of Sharp-shinned Hawks in New England. *J. Field Ornithol.* 67:254–267.

DUNN, E.H. AND D.L. TESSAGLIA. 1994. Predation of birds at feeders in winter. *J. Field Ornithol.* 65:8–16.

FRANSON, J.C., L. SILEO, O.H. PATTEE, AND J.F. MOORE. 1983. Effects of chronic dietary lead in American Kestrels (*Falco sparverius*). *J. Wildl. Dis.* 19:110–113.

GETZ, L.L., B.B BEST, AND M. PRATHER. 1977. Lead in urban and rural song birds. *Environ. Pollut.* 1977:235–238.

GILBERT, O.L. 1989. The ecology of urban habitats. Chapman and Hall Ltd., New York, NY U.S.A.

GIONFRIDDO, J.P. AND L.B. BEST. 1995. Grit use by House Sparrows: effects of diet and grit size. *Condor* 97:57–67.

HUNTER, J. 1986. The distribution of lead. Pages 96–126 *in* R. Lansdown and W. Yule [EDS.], Lead toxicity. Johns Hopkins Univ. Press, Baltimore, MD U.S.A.

KAPLAN, L. 2000. A tale of urban red-tails. *Bird Observ.* 28:250–251.

LOCKE, L.N. AND M. FRIEND. 1992. Lead poisoning of avian species other than waterfowl. Pages 19–22 *in* D.J Pain and I. Newton [EDS.], Lead Poisoning in Waterfowl. IWRB Special Publication 16, Slimbridge, U.K.

LOWTHER, P.E. AND C.L. CINK. 1992. House Sparrow. *In* A. Poole, P. Stettenheim, and F. Gill [EDS.], The birds of North America, No. 12. The Academy of Natural Sciences, Philadelphia, PA and The American Ornithologists' Union, Washington, DC U.S.A.

NATIONAL AUDUBON SOCIETY. 2002. The Christmas bird count historical records (online). http:www.audubon org/bird/cbc (accessed April 2002).

NEWTON, I. 1998. Population limitation in birds. Academic Press Inc., San Diego, CA U.S.A.

PETERLE, T.J. 1991. Wildlife toxicology. Van Nostrand Reinhold, New York, NY U.S.A.

RAPPOLE, J.H. 1995. The ecology of migrant birds: a neotropical perspective. Smithsonian Institution Press, Washington, DC U.S.A.

REDIG, P.T. 1984. An investigation into the effects of lead poisoning in Bald Eagles and other raptors: final report. Minnesota Endangered Species Program Study 100A–100B. University of Minnesota, St. Paul, MN U.S.A.

REISER, M.H. AND S.A. TEMPLE. 1981. Effects of chronic lead ingestion on birds of prey. Pages 21–25 *in* J.E Cooper and A.G. Greenwood [EDS.], Recent Advances in the Study of Raptor Diseases. Chiron Publications Ltd., West Yorkshire, U.K.

SODHI, N.S. AND L.W. OLIPHANT. 1993. Prey selection by urban-breeding Merlins. *Auk* 110:727–735.

VIVERETTE, C.B., S. STRUVE, L.J. GOODRICH, AND K.L. BILDSTEIN. 1996. Decreases in migrating Sharp-shinned Hawks at traditional raptor-migration watch sites in eastern North America. *Auk* 113:32–40.

WOOD, P.B., C. VIVERETTE, L. GOODRICH, M. POKRAS, C. TIBBOTT. 1996. Environmental contaminant levels in Sharp-shinned Hawks from the eastern United States. *J. Raptor Res.* 30:136–144.

Received 27 December 2002; accepted 14 September 2003

Associate Editor: Clint Boal